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RESEARCH DEPARTMENT

Mutual Interference between Naval Radar and VHF FM Broadcasting in Band II—B.B.C. and A.S.R.E. Tests

Report No. K-101
[1955/1]

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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1. SUMMARY.

Tests were carried out by the Admiralty Signal and Radar Establishment and the B.B.C. Research Department to investigate the mutual interference likely to arise from the co-channel operation of naval radar sets Type 281 and Type 960 with VHF FM broadcasting stations.

Specific measurements and observations on land in the Brighton area and at sea on board H.M.S. Boxer are described. It is concluded that perceptible interference would arise in coastal areas by the operation of the naval radar sets at sea out to ranges from the coast of the order of 70 km and 180 km in the case of the Type 281 and Type 960 sets respectively. The result of the tests on interference with the operation of the Type 281 set from a high power VHF transmitter cannot be regarded as conclusive as, for technical reasons, naval apparatus could not be adjusted to work exactly on the same frequency channel as the VHF FM transmitter. Tests indicate quite definitely, however, that a serious degree of interference with the radar may occur within ranges from a VHF FM transmitter of 250 km.

It is recommended that co-channel operation of the naval radar sets and VHF FM broadcasting should, if possible, be avoided, at least in coastal waters.

2. INTRODUCTION.

This report describes some tests arranged jointly by the Admiralty Signal and Radar Establishment and the B.B.C. Research Department to determine the extent of the mutual interference between the B.B.C. FM transmitters in Band II and the naval radar equipment working on shared frequencies within the band.

The sharing of some part of the frequency band 88–100 Mc/s between VHF broadcasting and naval radar arose in the following manner.

A document known as Paper Number 85 of the Inter-Departmental Committee on Post-War Planning shows that FM broadcasting in the United Kingdom has the exclusive

use of the frequency band 90·5 Mc/s to 95 Mc/s and that it shares the band 88 Mc/s to 90·5 Mc/s with the naval Type 281 set. The Paper further states that the naval Type 281 set has been granted priority on the frequencies 88 ± 0·5 Mc/s and 90 ± 0·5 Mc/s. It is stated that the allocations are based on agreements reached by the Inter-Departmental Committee before the Atlantic City Conference, but have been adjusted to fit within the framework of the allocation table agreed at the conference for the European Region. The European Broadcasting Conference (1952) provides for the use of the entire 88–95 Mc/s band by the United Kingdom for FM stations and assigns frequencies to particular stations.

3. GENERAL.

In June 1952 H.M.S. Swiftsure reported serious interference with her Type 281 radar from B.B.C. Wrotham FM transmissions. As a result of H.M.S. Swiftsure's report, trials were arranged between the B.B.C. and the Admiralty Signal and Radar Establishment (A.S.R.E.) to determine not only the nature and extent of the interference experienced by Type 281 from Wrotham but also that which Type 281 would cause to the reception of frequency modulated signals.

From the point of view of obtaining the maximum information about mutual interference, it was considered desirable to operate the interfering sources as near to one another as possible and then to increase the distance between them and note how the interference and field strength varied. For this reason the B.B.C. initially suggested carrying out the tests with a shipborne Type 281 in the Thames Estuary, the nearest sea point to Wrotham and one that offered a straight course for 130 km or more offshore in a N.W. direction. The ship allocated for the trials was, however, H.M.S. Boxer, a radar training unit which normally operates in the Isle of Wight area, and, as she was to carry out her normal training programme in addition to the A.S.R.E./B.B.C. trials, the tests were of necessity carried out in this area.

A B.B.C. Research Department Report A-021——"Radar Pulse Interference"—— gave the results of some preliminary work on the problem carried out in 1946 when measurements were made on a naval radar transmitter at Chatham. The work now described is a more complete investigation embracing subjective listening tests and the effect of the jamming of the naval radar by a high power VHF transmitter.

The Radio Branch of the Post Office Engineering Department was informed of the tests and sent observers to one of the B.B.C. receiving sites and to H.M.S. Boxer.

4. PROGRAMME OF TRIALS.

Tests were initially planned for two consecutive days, as follows:

First day

1. H.M.S. Boxer to steam from a point off Worthing on the continuation of a straight line joining Wrotham and the B.B.C. shore site (see 5 below) towards Cherbourg.

2. Measurements of the field strength of Wrotham on 91·4 Mc/s to be made periodically on board.

3. The Type 281 radar set to be tuned to 91·4 Mc/s and adjusted for the radiation of a peak effective power of 3·2 MW in the direction of maximum aerial gain.

4. The interference from the Wrotham transmission to the Type 281 set receiver display to be noted and, if possible, photographically recorded.

5. B.B.C. observations to be made at Shoreham-on-Sea at a site effectively at sea level.

Second day

1. H.M.S. Boxer to steam on course approximately the reciprocal of that of the first day.

2. Field strength and interference measurements and observations to be made on board as on the first day.

3. B.B.C. observations to be made at a high site on the South Downs near Brighton (initially planned as Truleigh Hill but later changed to the Dyke Golf Club House).

The tests originally planned for two days, as above, were conducted on 1st, 2nd and 3rd February, 1954.

The observations made at the B.B.C. site consisted of:

a. measurements of the Wrotham field strength;

b. measurements of the field strength of the signals from H.M.S. Boxer;

c. subjective assessment of the degree of interference to the required programme from Wrotham.

A change in the programme was necessitated by a mis-match between the Type 281 feeder and aerials on a frequency of 91·4 Mc/s. This had caused the Pyrotenax feeder to be damaged when an attempt was made to radiate a peak power of 3·2 MW. The trials were, therefore, carried out with a Type 281 transmitter unit operating on a frequency of 90·3 Mc/s and a reduced ERP of 0·8 MW.

A second radar set, Type 960, a modern counterpart of the Type 281, also radiated during the trials. This set, though capable of operating at frequencies up to 90 Mc/s, is not at present permitted to operate in the 88–90·5 Mc/s band. The B.B.C., however, took advantage of the facilities offered by A.S.R.E. and subjective tests were carried out to determine its effect on FM broadcasting.

The measurement of the amplitude of the pulses of the two radar sets was made with a modified Gee receiver fitted with anti-jamming circuits. A locally generated pulse from a standard signal generator was coupled into the Gee receiver and its width and amplitude adjusted until it was equal to that received from the radar sets. With this arrangement, it was possible to measure the field strength of the pulses when their amplitude was 35-40 dB below that of a co-channel FM signal.

Further data of transmitting and receiving equipment, site and aerial heights are given in the Appendix.

5. INTERPRETATION OF FIELD STRENGTH MEASUREMENTS.

Before discussing details of the observations, the method of evaluating the field strength measurements both on ship and shore is described. On account of fading, it was necessary to observe the field strength of Wrotham on H.M.S. Boxer for a period of 1-2 minutes and note the mean value. This was done at least once every fifteen minutes and on completion of each run the mean measured value was related to distance from Wrotham by reference to the ship's log.

Field strength measurements on board H.M.S. Boxer could only be made conveniently at a height of 9·8 metres above sea level, although the height of the aerial system of the Type 281 radar set was 35 metres above sea level. It is, therefore, necessary to make a correction to the measurements made at the lower height in order to arrive at values for the field incident on the Type 281 set aerial. This has been done on a linear height gain basis, the gain factor being 3·6. This is likely to be the true gain for all ranges where the ship is below the radio horizon from the last diffracting ridge on the wave path from Wrotham (the South Downs) but for closer ranges the linear height gain may not apply. Since the ranges at which the interference effects were observed extend well beyond this horizon, all the figures given in this report for the field strength of Wrotham on H.M.S. Boxer include the linear height gain correction.

The receiving aerials at the shore sites were all at a height of 9·2 metres above ground level, the value (30 ft) being the height above ground generally accepted as the height of the average listener's outdoor aerial.

Fading was observed on the signals received from H.M.S. Boxer at a distance exceeding 65 km. Allowance has, however, been made for this by a process of averaging.

All measured field strengths of the Type 281 set have been corrected for the normal power of 3·2 MW and the distances corresponding to various degrees of interference from the Type 281 set have likewise been corrected.

6. INTERFERENCE WITH TYPE 281 RADAR FROM WROTHAM.

As the Type 281 transmitter unit could not be tuned to Wrotham's frequency, it was impossible to observe co-channel interference under normal working conditions and recourse was made to tuning the receiver unit to 91·4 Mc/s while the transmitter unit radiated on 90·3 Mc/s. In this mis-tuned condition no echoes appeared on the

receiver displays but the effect of the interference could be observed on either cathode ray tube trace, as the aerial rotated through 360°.

The effect of the FM signal on the display was as follows:

As the amplitude of the interference signal increased, the trace level rose and the noise amplitude decreased. Further increase of the interference level caused the datum line of the trace to limit and the noise to invert. This condition was observed when H.M.S. Boxer was 200 km from Wrotham and the Type 281 aerial was pointing towards Wrotham; the corresponding field strength was 20 μV/m. Still further increase of the field strength reduced the amplitude of the noise to zero and the cathode ray tubes then gave a clean trace. This condition corresponded to a field strength of 45 μV/m.

When the interfering field strength exceeded 400 μV/m, it was possible to observe both the interference and echoes by tuning the receiver unit to a point mid-way between 90·3 Mc/s and 91·4 Mc/s. In this condition, similar effects were noted to those described above.

Table 1 summarises the result of the observations as the distance between H.M.S. Boxer and Wrotham was progressively decreased.

TABLE 1

Summary of Subjective Tests on Type 281 Radar
with Wrotham as the Source of Interference

Distance from Wrotham——km	Approximate Field Strength——μV/m	Interference
200	20	Trace limiting over an arc of 40° and noise inverted
175-185	45	Trace wiped clean over an arc of 40°
170-175	63	Weak interference on back lobe in addition to above
165	80	Weak interference on side lobes in addition to above
140	250	Saturation jamming on all bearings except arc of 40° on each side
130	400	Saturation jamming on all bearings

The table shows that when the ship was 200 km from Wrotham, the Type 281 set was inoperative over an arc of 40°, and at 130 km from Wrotham, the set was completely inoperative on all bearings. These conditions correspond to field strengths of 20 μV/m and 400 μV/m respectively.

The ground profile between the Wrotham transmitter and the course seawards from a point off Worthing is not very favourable for VHF transmission owing to the attenuation introduced through diffraction losses, by the South Downs which rise to a height of about 700 ft. To indicate the ranges at which interference with the Type 281 radar set may be experienced when the ground profile outwards from the transmitter is more favourable Table 2 below has been prepared. Here the distance ranges have been derived from theoretical propagation curves for propagation over average terrain (F.C.C. data, U.S.A.) and apply to a 90 Mc/s transmitter with an effective radiated power of 125 kW and height of aerial of 1000 ft above the surrounding terrain.

TABLE 2

Probable Range of Interference with Type 281 Radar
from Typical High Power VHF FM Transmitting Site

Distance from FM Station (ERP 125 kW, aerial height 1000 ft) km	Interference
250	Trace limiting and noise inverted over an arc of 40°
200	Trace wiped clean over an arc of 40°
185	Weak interference on back lobe in addition to above
176	Weak interference on side lobes in addition to above
145	Saturation jamming on all bearings except for 40° arc on each side
132	Saturation jamming on all bearings

Under abnormal tropospheric propagation conditions the above ranges may be considerably increased and the operational use of the Type 281 set would be further restricted.

The A.S.R.E. representative on board H.M.S. Boxer decided to conduct the tests without the anti-jamming circuits of the Type 281 set connected, for the following reasons:

i. Under the particular conditions of the tests (Wrotham and the Type 281 set operating on different frequencies), it was considered that the results would be so unrealistic as to be misleading.

ii. Anti-jamming circuits severely restrict the operational use of the equipment in a number of ways.

7. INTERFERENCE WITH FM BROADCASTING FROM TYPE 281 RADAR.

Subjective co-channel listening tests on Wrotham's frequency with the Type 281 set as the source of interference could not be carried out as planned because, as mentioned earlier in this report, the Type 281 set could not be tuned to 91·4 Mc/s. This difficulty was, however, overcome by tuning the FM receiver to the Type 281 set pulse transmissions on 90·3 Mc/s and injecting a locally generated frequency modulated signal derived from a standard signal generator.

The signal generator was modulated with programme and the output level was adjusted to correspond to the appropriate field strength at each receiving post, i.e. 0·5 mV/m at Shoreham and 9·0 mV/m at Dyke Golf Club House. It was thus possible to observe the co-channel interference effect of Type 281 and, by retuning the local signal generator, similar observations were made for Type 960 radiating on 86 Mc/s. The field strength of both radar sets was measured periodically on a modified Gee receiver at both receiving posts. The results of the observations on interference from the Type 281 set are given in Table 3.

TABLE 3

Summary of Subjective Tests on an FM Signal with Type 281 Radar as the Source of Interference

Amplitude of pulse relative to that of the FM carrier dB	Distance from H.M.S. Boxer km		Degree of Interference
	Shoreham (Wrotham 0·5 mV/m)	Dyke Golf Club House (Wrotham 9·0 mV/m)	
−10	82	110	"Just perceptible" when carrier unmodulated
0	66	87	"Perceptible" when carrier unmodulated
+10	47	64	"Perceptible during quiet passages in programme
+20	32	48	"Perceptible" on programme of average modulation level
+30	19	34	"Slightly disturbing" on programme of average modulation level
+40*	11*	18*	"Disturbing" on programme of average modulation level

*These figures were obtained by extrapolation of the field strength/distance curve for Type 281 and laboratory tests.

Before commencing on this table, it should be noted that the nearest H.M.S. Boxer approached Shoreham was 15 km while the corresponding distance for Dyke Golf Club House was 42 km. The data shown in the table for smaller distances were derived by interpolation of the field strength/distance curves for the Type 281 set and laboratory tests subsequent to the trials.

The table shows that at Shoreham the degree of interference varied from "just perceptible" when the carrier was unmodulated for H.M.S. Boxer 82 km distant, to "disturbing" when she was 11 km distant. For the distances at which observations were made the level of interference was never "very disturbing".

The distance between H.M.S. Boxer and Dyke Golf Club House for a given degree of interference is considerably greater than that for the Shoreham site; this arises from the fact that the field strength of the Type 281 set was greater, relative to that of Wrotham, at Dyke Golf Club House than at Shoreham. This is readily seen from Fig. 1 which makes direct comparison between the measured and theoretical field strengths for both sites. The difference between the theoretical fields is 27 dB, whereas the average difference between the measured fields is 34 dB. The discrepancy between each measured field strength curve and the appropriate theoretical one is well within the limits imposed by local site conditions.

The two receiving sites, one at sea level and one elevated on a high, clear site, tend towards the extremes in elevation and it is considered that a typical receiving site would lie somewhere between these limits. For this reason, a fifth curve has been drawn on Fig. 1. This curve is for a field strength 10 dB greater than the theoretical value for Shoreham, and, although arbitrary, it is considered to be fairly representative of the field strength of the Type 281 set at a typical coastal town.

Considering now the whole problem of interference from the Type 281 set in more general terms, and taking the European Broadcasting Conference, Stockholm, 1952, recommendation that a field of 0·25 mV/m should be protected for 99% of the time, Table 4 has been drawn up, based on the theoretical curves of Fig. 1. It gives the distances between a shipborne Type 281 set and three receiving sites, one at sea level, one "typical", and one elevated, for various levels of interference. From the table it will be seen that, due to the reduction in the protected field strength to 0·25 mV/m compared with that of Wrotham, the distances at which a given level of interference would be observed are considerably greater than those measured and shown in Table 3. This is particularly so in the case of Dyke Golf Club House site, where the field strength of Wrotham is 9·0 mV/m.

The use of theoretical rather than the measured field strengths is also responsible for minor differences on both sites but it is preferable to employ "standard" field strengths when dealing with the general case.

In interpreting Tables 3 and 4, it should be borne in mind that when the distance between the source of interference and the receiver exceeds 70–80 km, abnormal tropospheric conditions would raise the level of interference above that shown in the tables.

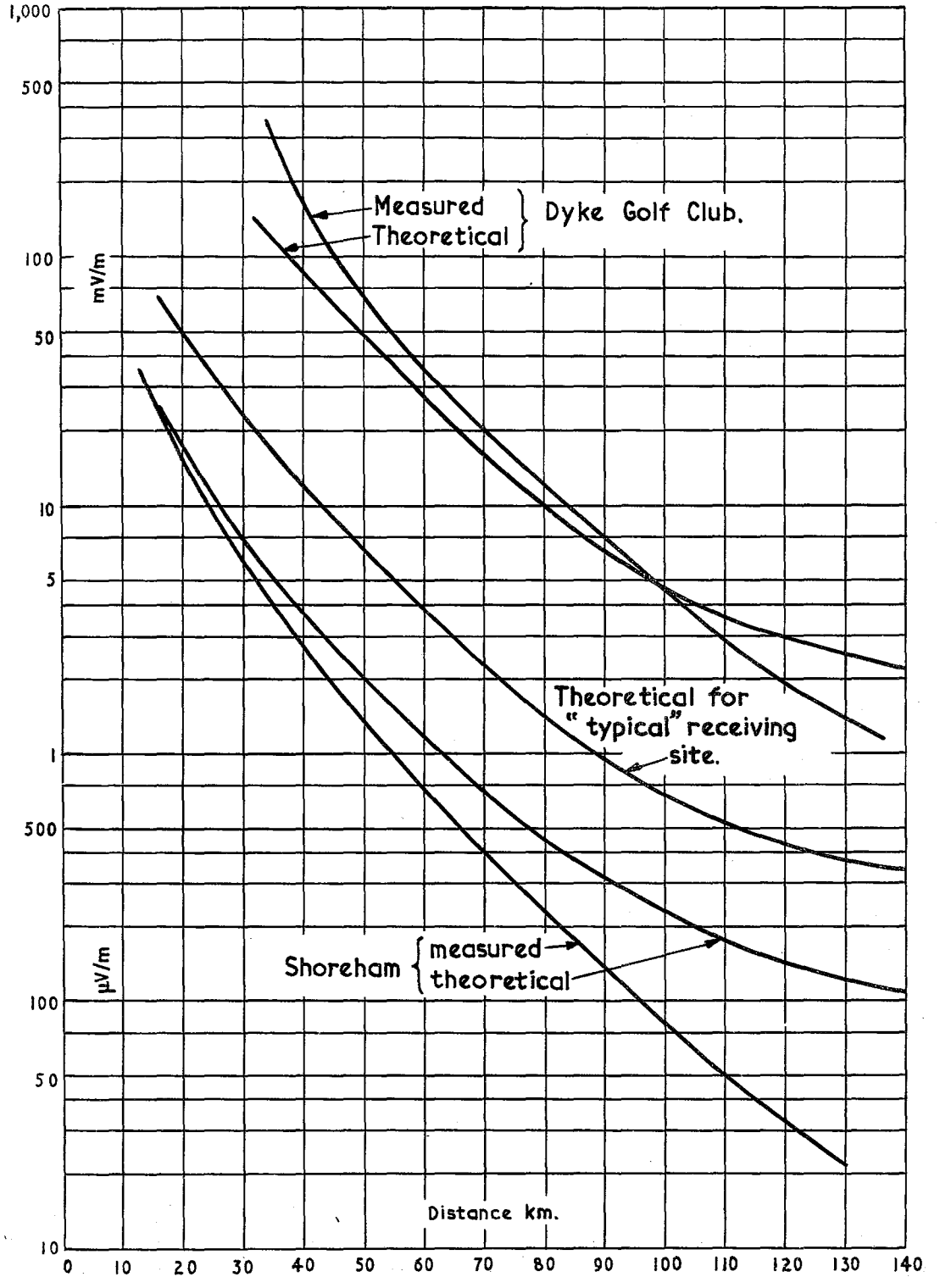

Fig. 1 - Field strength of Types 281 and 960 radar transmitters at B.B.C. receiving sites

TABLE 4

Interference between Type 281 and an FM Broadcasting Service for three Receiver Sites

(FM Carrier Field Strength = 0·25 mV/m)

Degree of Interference	Distance from Shipborne Type 281 km		
	Site at sea level	"Typical" site	Elevated site
"Just perceptible" when carrier unmodulated	158	240	440*
"Perceptible" when carrier unmodulated	98	156	320*
"Perceptible" during quiet passages in programme	67	95	220
"Perceptible" on programme of average modulation level	46	69	132
"Slightly disturbing" on programme of average modulation level	30	46	86
"Disturbing"	16	29	60

* These figures were obtained by extrapolation of the field strength/distance curve for Type 281 and laboratory tests.

8. INTERFERENCE WITH FM BROADCASTING FROM TYPE 960 RADAR.

The Type 960 radar set is the modern counterpart of Type 281 and the only significant difference in their transmission characteristics is that the Type 960 set has a pulse repetition frequency of 250 c/s and the Type 281 set a pulse repetition frequency of 100 c/s.

The interference tests using the Type 960 set as the source were carried out in precisely the same way as those described for the Type 281 set and Table 5 is a summary of these interference observations.

TABLE 5

Summary of Subjective Tests on an FM Signal with Type 960 Radar as the Source of Interference

Amplitude of pulse relative to that of the FM carrier dB	Distance from H.M.S. Boxer km		Degree of Interference
	Shoreham (Wrotham 0·5 mV/m)	Dyke Golf Club House (Wrotham 9·0 mV/m)	
-27	135	158	"Just perceptible" when carrier unmodulated
-13	87	110	"Just perceptible" during quiet passages
- 7	74	96	"Perceptible" during quiet passages
- 3	67	90	"Perceptible"
0	63	85	"Slightly disturbing"
+ 3	58	80	"Disturbing"
+20	29	45	"Very disturbing"

Comparison between Tables 3 and 5 shows that the Type 960 set causes a much higher level of interference than the Type 281 set. For example, when the field strength equalled that of the wanted FM transmission, the level of interference was "slightly disturbing", whereas the corresponding level for the Type 281 set was "perceptible when the carrier is unmodulated". Further comparisons for the same radar field strengths are "very disturbing" and "perceptible on programme of average modulation level". These comparisons clearly show that, as expected, the set with the higher pulse repetition frequency causes the higher interference level.

The measured field strength/distance curves for this set are almost exactly the same as those for the Type 281 set shown in Fig. 1.

Both sets being of equal power, the same theoretical curves are used to derive the distances for various levels of interference at three representative receiver sites. The protected field strength considered is again 0·25 mV/m and the results are given in Table 6.

TABLE 6

Interference between the Type 960 set and an FM Broadcasting Service for three Receiver Sites

(FM Carrier Field Strength = 0·25 mV/m)

Degree of Interference	Distance from Shipborne Type 960 km		
	Site at sea level	"Typical" site	Elevated site
"Just perceptible" when carrier unmodulated	320	–	–
"Just perceptible" during quiet passages in musical programme	184	420*	–
"Perceptible during quiet passages in musical programme	138	218	406*
"Perceptible" on programme of average modulation level	116	182	350*
"Slightly disturbing" on programme of average modulation level	98	160	320
"Disturbing" on programme of average modulation level	87	136	290
"Very disturbing" on programme of average modulation level	46	70	132

*These figures were obtained by extrapolation of the field strength/distance curve for the Type 281 set and laboratory tests.

9. CONCLUSIONS.

The experiments have shown that considerable mutual interference would result if the naval radar sets are operated on shared frequency channels with VHF FM broadcasting.

In particular, the interference suffered by the radar system might be such as to render it inoperative in a ship within 200 km of a typical inland transmitter

site of the "high power" type the B.B.C. proposes to use. In the exceptional case of a high power FM transmitter on a high site near the coast, intolerable interference might be suffered by the radar system out to ranges of 250 km.

The converse interference with FM broadcasting is not quite so serious in terms of range but the tests show that, in the case of a typical receiving location, at average height above sea level and near the coast, interference graded as "perceptible" or worse would be experienced when the shipborne radar was within 70 km of the coast in the case of the Type 281 set, and within 180 km in the case of the Type 960 set. In arriving at the above figures it is assumed that a second-class service of 0·25 mV/m would be available to the listener.

Some of the results of the trials described in this report require qualification since the co-channel tests were not carried out as originally planned. In particular, it is considered that if the interference experienced by the Type 281 set had been assessed in the presence of radar echoes it might not have been quite so extensive as that indicated against a background of receiver noise. Furthermore, co-channel tests would have provided data of a more detailed nature, showing the effect of the interference on various aspects of the performance of the Type 281 set. Likewise, tests with the Type 281 set using its anti-jamming circuits would have provided data showing not only the extent to which they limit its performance in the absence of interference but also that to which they enhance its performance in the face of co-channel interference.

The tests to determine the extent to which an FM service would suffer from co-channel operation of either the Type 281 or Type 960 set are not subject to the same limitation, since, in this case the co-channel conditions simulated by using a locally generated FM signal are regarded as satisfactory.

The results of the tests provide strong support for the recommendation that, if possible, co-channel working of FM broadcasting and the naval radar sets should be avoided altogether or, if this is not possible, the use of the naval radar sets should be restricted to sea areas at sufficient distance from the coast that there is no possibility of mutual interference.

APPENDIX

EQUIPMENT ON H.M.S. BOXER

	RADAR UNITS	
Transmission Characteristics	Type 281	Type 960
Pulse repetition frequency (c/s)	100	250
E.R.P. MW (max.)	0·8	3·2
Aerial height (ft)	115	115
Frequency (Mc/s)	90·3	86

Field Intensity Meter : R.C.A. Type 301B (modified)

EQUIPMENT AT B.B.C. RECEIVING POST

C.W. Field Intensity Meter : R.C.A. Type 301B (modified)

For measurement of pulse amplitude : Gee receiver Type 1355 (modified) Type 27 (modified) R.F. Units plus pre-amp.

Oscilloscope : Cossor Type 1035

Standard signal generators : Marconi Types TF.801A and TF.995

F.M. Receiver : Fitton and Eddystone Type 770R

Pulse Generator : B.B.C.

A.F. Oscillators : B.B.C. and Ediswan Type R.666

SITE DATA

	WROTHAM	SHOREHAM	DYKE GOLF CLUB HOUSE
Latitude	51° 19′ 11″ N	50° 49′ 54″ N	50° 52′ 51″ N
Longitude	00° 17′ 20″ E	00° 14′ 55″ W	00° 12′ 24″ W
National Grid Reference	TQ (51)/594604	TQ (51)/234051	TQ (51)/251107
Site height (ft) a.m.s.l.	720 (216 m)	20 approx. (6 m)	670 approx. (190 m)
Distance from Wrotham (miles)	-	41·5 (67 km)	38 (61 km)